AD-A228 758

REPORT DOCUMENTATION PAGE

Form Approved OMB No 0704-0188

2. REPORT DATE	October, 1990
3. REPORT TYPE AND DATES COVERED	Annual Letter Report for FY90
4. TITLE AND SUBTITLE	Research and Development on Advanced Silicon Carbide Thin Film Growth Techniques and Fabrication of High Power and Microwave Frequency Silicon Carbide-Based Device Structures
5. FUNDING NUMBERS	R&T:212k003---03
6. AUTHOR(S)	Robert F. Davis
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)	North Carolina State University, Hillsborough Street, Raleigh,NC 27695
8. PERFORMING ORGANIZATION REPORT NUMBER	N00014-88-K-0341/ P00002
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	Sponsoring: ONR, 800 N. Quincy, Arlington, VA 22217 Monitoring: Office of Naval Research Resider, N66005, The Ohio State Univ. Research Center, 1314 Kinnear Road, Columbus, OH 43212-1194
10. SPONSORING/MONITORING AGENCY REPORT NUMBER	
11. SUPPLEMENTARY NOTES	
12a. DISTRIBUTION/AVAILABILITY STATEMENT	Approved for Public Release; Distribution Unlimited
12b. DISTRIBUTION CODE	

13. ABSTRACT (Maximum 200 words)

alpha

In this reporting period the RF operation of bipolar transistors fabricated from α(6H)-SiC have been theoretically modeled and the dc and RF performance of a MESFET fabricated in α-SiC by Cree Research investigated and improved from the standpoints of parasitic resistances and capacitances as well as device design and fabrication procedures. In addition IMPATT diode structures have been further developed, ohmic and Schottky contact materials selected and deposited and the design and construction of a new MBE/ALE system virtually completed.

Keywords: Impatt diodes; Bipolar transistors; Silicon carbides; THIN films. (RH)

14. SUBJECT TERMS	alpha SiC, theoretical models, MESFETs, IMPATTs, ohmic and Schottky contacts, MBE/ALE deposition
15. NUMBER OF PAGES	10
16. PRICE CODE	

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLAS	UNCLAS	UNCLAS	SAR

Annual Letter Report for FY 90

(1) Contract Title: Research and Development on Advanced Silicon Carbide Thin Film Growth Techniques and Fabrication of High Power and Microwave Frequency Silicon Carbide-based Device Structures

Contract Number: N00014-88-K-0341/P00002

Principal Investigator: Dr. Robert F. Davis

Department of Materials Science and Engineering
North Carolina State University
Box 7907
Raleigh, NC 27695-7907
Tel: (919) 737-3272

Program Manager: Dr. Y. S. Park, Code 1212, ONR

(2) Technical Objectives:

- **Device simulation of the RF potential of various electronic device structures fabricated in SiC. Simulation of the operation of the devices under realistic operating conditions and comparison of their RF performance to comparable devices fabricated from the more commonly used semiconductors of Si and GaAs.** In this manner, specific devices most suitable for fabrication in SiC can be identified. The experimental characterization effort supports both the simulator development effort and the device fabrication work. Prototype devices are fabricated and tested to determine dc and RF characteristics. The measured data is compared to the simulated results to verify the models and to provide direction as to important physical effects that need to be modeled. The feedback allows improvements to be made, thereby permitting accurate, advanced device models to be developed. The models are then used to provide guidance for improved device designs.

- **Increase the power handling capability of high frequency solid-state devices by developing a silicon carbide power metal-semiconductor field-effect transistor (MESFET) and impact ionization avalanche transit time (IMPATT) diode.** Although MESFETs developed in this program will be designed to output 45 W in the 10 GHz frequency range, it is anticipated that the power and frequency could be limited due to potential fabrication problems involving these large area, fine geometry devices. The primary deliverable of this contract will be a SiC MESFET which will output 40 W of power at $\geq$ 1GHz.

- **Relate the ohmic and Schottky behavior of specific metal contacts on chemically-clean 6H-SiC to microstructure and chemistry at the interface.**

- **Design, commission, and construct system for ultra-high vacuum growth and doping of SiC thin films on α(6H)-SiC substrates using molecular beam epitaxy (MBE). Determine and optimize output characteristics of**

electron cyclotron resonance (ECR) plasmas used for decomposition of carbon source, nitrogen (n-type species) source, and hydrogen *in situ* cleaning of SiC substrates. Conduct experiments to optimize conditions for growth of pure and doped SiC films. Characterize films using established analytical and electrical techniques.

(3) Approaches to Achieve the Objectives:

- Theoretical models for various types of electronic devices are being developed. The work has concentrated so far upon MESFET and IMPATT models developed at NCSU and models for bipolar transistors available in commercial RF simulators. More accurate bipolar models are currently under development at NCSU. The models are being improved by the addition of physical effects found to be of importance. The model enhancement work has thus far involved the development of algorithms for thermal effects, breakdown phenomena, and parasitic elements. The additional features are being incorporated into the basic device simulators.

  A characterization procedure for investigating the RF performance of prototype devices is also being developed. The characterization facility allows dc, microwave (currently up to 26.5 GHz), thermal, and parasitic measurements to be performed using an on-wafer procedure.

- The portion of the program at Cree Research, Inc. is focused on the production of high power, high frequency SiC MESFETs and the measurement of the RF power output. The approach involves the achievement of several necessary intermediate objectives such as determining the optimum device designs for the best overall characteristics, reducing parasitic source/drain resistance, parasitic gate capacitance, and methods for obtaining self-aligned gates.

- Based on barrier height calculations between a host of metals and SiC, the metals of Ti, Hf and Ni have been selected as the most promising candidates for ohmic contacts on n-type SiC (the only type currently available to the investigators). For Schottky contacts on the same material, Pt and Sr were selected as the materials with the most promise. All materials have been purchased in the highest purity available and in the proper form. The n-type SiC wafers or epitaxial films on these wafers supplied to NCSU by Cree Research, Inc. are used as the base on which several cleaning procedures (standard RCA, ultraviolet light-ozone and remote plasma) have been or will be examined in order to produce a surface free of oxide and hydrocarbon films. The deposition of the metals is being conducted via thermal and electron beam evaporation. The structural relationships between each metal and the (0001) Si surface as well as the resulting interface chemistry is being studied using low energy electron diffraction (LEED), x-ray photoelectron spectroscopy (XPS), Rutherford backscattering spectrometry (RBS), ultra-violet photoelectron spectroscopy (UPS) and Auger electron spectroscopy (AES).

- The all metal MBE system has been constructed and the last parts are being installed. The SiC substrates will be cleaned *in-situ* prior to deposition. Plasma decomposition will be used to assist the deposition of C and N as well as surface cleaning with H. Disilane, pure Al, and N_2 will be used as the sources of Si and the dopants of Al and N, respectively.

(4) Accomplishments:

- The RF operation of the MESFETs and bipolar transistors fabricated from both α(6H)-SiC and β-SiC has been investigated theoretically at NCSU. Typical device structures have been designed, optimized, and their RF performance simulated. The relatively low electron mobility of α-SiC ($u_n = 240\ cm^2/V\text{-sec}$) and the extremely low hole mobility ($u_p = 50\ cm^2/V\text{-sec}$) of this material severely limit the RF performance of SiC bipolar transistors, especially at microwave frequencies. Bipolar transistors fabricated from α-SiC are most likely limited in frequency performance to approximately S-band (i.e., 2-4 GHz). Above this frequency the large parasitic resistances resulting from the lower carrier mobilities and the relatively small area devices required at microwave frequencies significantly degrade both RF output power and power-added efficiency. At S-band and below, however, large RF output power is available. Our calculations indicate that at 3 GHz, approximately 31 W RF power, a maximum power-added efficiency of 16%, and a linear gain of 8.5 db can be achieved in α-SiC bipolar transistors. The large output power results from the large RF voltage that can be sustained due to the high breakdown voltage of the material. The larger electron and hole mobilities of β-SiC will increase the RF performance of bipolar transistors, possibly to X-band.

  The MESFET device appears to be near ideal for utilizing the materials properties of SiC, especially for RF power applications. The most critical consideration in utilizing SiC for MESFETs is the requirement that velocity saturation be achieved under the gate electrode. Low electron mobility indicated the need for high bias voltages. However, high drain bias voltage generally results in reverse breakdown conditions being achieved at the gate Schottky contact. This factor prevents Si, which has an electron mobility in the same range as SiC, from being effectively utilized as a material for fabrication of power microwave MESFETs. The rapid development of the technology under ONR sponsorship for producing high quality single crystal silicon carbide (SiC) wafers and thin films presents the opportunity to fabricate microwave solid-state devices with RF power-frequency capability far greater than devices currently available. Silicon carbide has a much higher critical field for breakdown, and much higher bias voltages can be sustained, thereby permitting microwave power devices to be fabricated. Gate breakdown voltages of about 100 V are possible, permitting drain bias voltages of 40 V to be sustained. This in turn, allows velocity saturation to be achieved. Our calculations indicate that output powers of 630 W, 158 W and 45 W can be produced at 0.5, 3 and 10 GHz respectively, in a SiC MESFET. At the 45 W RF output power level, a 27% power-added efficiency and 6.5 db gain may be realized. The relatively low mobilities obtained with SiC do not seriously degrade parasitic resistances due to the large area contacts employed. The normalized RF output power is approximately 2.8 W/mm, which compares favorably with the 0.5-1 W/mm obtained using GaAs.

- The primary hindrance to SiC development in the past has been the inability to produce large, high quality SiC crystals suitable for device fabrication. Cree Research is currently producing production 1" diameter SiC wafers and will scale up to 1.5" production in early 1991 and 2" in early 1992. In addition, the defect density of SiC epitaxial films has decreased by a factor of 1,000,000 under ONR sponsorship. This dramatic increase in material quality now allows the fabrication of a variety of SiC devices with excellent electrical characteristics.

As noted above, computer modeling of SiC microwave MESFET and IMPATT devices had been conducted at NCSU. For a frequency of 10 GHz, the MESFET was calculated to produce 2.5 W/mm of gate length which translates to a maximum power output of 45 W at 10 GHz for a single device. Cree has developed an excellent Schottky contact for the MESFETs that not only operates at high electric fields, but also at high temperatures (350°C). Low frequency FETs which operate to drain-source voltages of 100 V have been produced, and preliminary high frequency devices have demonstrated an f_{max} as high as 900 MHz and an f_t = 1.75 GHz. This program has produced the only high frequency characteristics ever reported for a SiC device, and these high frequency parameters have increased by a factor of 10 in the past year. A second generation device which addresses the known frequency limiting factors in the first iteration has been designed.

- In an effort to define a process to create a chemically-clean surface, analyses of 6H-SiC surfaces have been performed at NCSU with x-ray photoelectron spectroscopy (XPS) before and after *ex-situ* cleaning. XPS analysis of an 'as-received' SiC wafer indicated the presence of fluorine, oxygen, and hydrocarbons. The wafer was subsequently given an RCA clean: 10 min. in H_2O / H_2O_2 / NH_4OH (5 : 1: 1) at 70°C, 5 min. in DI water, 10 min. in H_2O / H_2O_2 / HCl (5 : 1 : 1) at 70°C, 5 min. in DI water. To etch the oxide the wafer was dipped in 49% HF immediately prior to analysis. XPS results showed slight reduction of all of the above surface contaminants. After exposing a wafer to an ultraviolet light/ozone generator and a subsequent 10% HF solution, XPS analysis still indicated the presence of fluorine; however, the amounts of oxide and hydrocarbons were significantly reduced. Although the XPS results indicate reduction in surface contaminants, some still remained, indicating the need for *in-situ* cleaning.

Titanium was deposited on 6H-SiC which had been given an RCA clean/49% HF dip. Deposition was from a hot wire filament onto a substrate surface which was at room temperature. After depositing a 400 A thickness in 100 A steps, the sample was annealed to 900°C in 100°C steps for 10 min. at each step. Auger electron spectroscopy and low energy electron diffraction (LEED) were performed after each deposition/anneal. The presence of Si and C near the surface was not detected in the Auger spectra until annealing to 500°C. In addition, all of the LEED patterns showed the same $\sqrt{3} \times \sqrt{3}$ pattern identical to the bulk SiC, while channeling occurred for a particular substrate orientation during Rutherford backscattering (RBS). The results suggest that room temperature deposition of Ti on 6H-SiC results in crystalline Ti with a pseudomorphic structural relationship with SiC substrate.

The Auger results give evidence that the kinetics at 500°C will be satisfactory for studying chemical phase formation as a function of time. Subsequent to exposing a wafer to uv/ozone and 10% HF dip, 200A of Ti was deposited at room temperature through a shadow mask and annealed at 500°C for 25 min. Both a small Si peak and a small C peak were present in the Auger spectrum, while the LEED again showed the $\sqrt{3} \times \sqrt{3}$ pattern.

Contact diodes were fabricated by depositing a uniform backside Ti layer at 400°C and then depositing a frontside Ti dot pattern (25, 50, and 100 mil diameter) through a shadow mask. In one case the frontside metal was deposited at room temperature and not annealed. Linear current - voltage measurements showed rectification with soft breakdown at approximately –6V. In another case the frontside metal was deposited at 400°C, for which the current - voltage characteristics were still rectifying but with

more ohmic-like behavior. These results suggest the possibility of forming an ohmic contact at high temperature.

- The molecular beam/atomic layer epitaxy (MBE/ALE) system has been designed, commissioned, and the assembly is virtually completed. This system consists of a small chamber used for loading of samples and a larger chamber where *in situ* sample cleaning and film growth will take place. Both chambers are now installed and nearly all components are in place. A tungsten filament heater specially designed for this system has been built and was installed last month.

  Growth species to be used in growth of SiC consist of disilane (Si_2H_6) as the Si source and ethylene (C_2H_4) introduced downstream of an ECR Ar^+ plasma as the carbon source. In addition, doping of films will be performed using solid Al from an MBE effusion cell and N_2 decomposed using an ECR plasma. Samples will be cleaned using hydrogen introduced downstream from an electron cyclotron resonance (ECR) Ar^+ plasma. The fabrication of the ECR sources is virtually completed. We are still awaiting the delivery of the power supplies in these sources.

  Control of source flux in the molecular flow regime will be achieved using a pressure-based flow control system capable of very precise control of process gases. Control of gas flow is based on measurement of the pressure drop across an element of constant conductance. Both mechanical shutters and this pressure-based flow control system have been installed for each source gas in this system to allow for rapid switching of sources.

(5) Significance:

The Navy has a strong need for high power solid-state microwave devices to replace the bulky and unreliable TWT technology currently used. Moreover, the power vs. frequency output of state-of-the-art microwave devices produced from silicon or gallium arsenide has become material limited and does not meet present needs. The properties of silicon carbide will allow development of devices with a greatly increased power-frequency relationship. Silicon carbide microwave devices will solve many problems in existing radar and communications systems and provide the basis for development of greatly advanced systems. A 1 GHz SiC device which can output 50 W would make spectacular improvements over what is presently available for solid-state phased array radars and would save the government more than $300,000,000 over the next five years. The ability of SiC devices to operate at high temperatures (350°C) at high frequency will make them invaluable for modern avionic instrumentation where cooling problems are becoming increasingly critical. Solid-state megacycle power supplies are also envisioned.

To achieve the full capabilities of the above devices, low resistance ohmic contacts and Schottky contacts with excellent rectification characteristics must be achieved. Research to determine the optimum materials (metals or their compounds) with SiC is being conducted under the cleanest possible conditions with the lowest concentration of impurities possible in terms of the SiC, the contact materials and the deposition and analysis systems. Having determined the proper materials and conditions for their deposition, this knowledge will be immediately passed to the industrial section for incorporation into device fabrication scheme.

The MBE/ALE system will be capable of lower-temperature, mono-crystalline growth of SiC than other methods currently in use. Controlled decomposition of ethylene using an ECR plasma should ease somewhat the requirement that large

amounts of thermal energy be supplied to the sample surface, thus allowing for a lower sample temperature during SiC growth. In addition, the purity of SiC films grown using this system should be extremely high, as samples will be cleaned *in situ* prior to growth, and deposition will occur in a UHV environment. Both these factors should result in a lowering of defects present in grown films, and thus a potential increase in quality of electrical characteristics such as mobility.

(6) Future Efforts:

The theoretical calculations will be extended to include a thorough analysis of thermal and breakdown effects. Both of these phenomena are fundamental to the operation of electronic devices. The tandem characterization effort will be continued and recently fabricated MESFETS will be characterized and the RF performance compared to the theoretical calculations.

Some of the major parasitics that still limit the performance of the high frequency 6H-SiC MESFETs are gate length, gate capacitance, and gate resistance. The new design mentioned above should allow further reduction of all of these parasitics. New gate contact pad isolation layers are being investigated to further reduce gate capacitance. Methods of obtaining thicker metal overlayers for the gate are being explored so that gate resistance can be reduced. Much of the effort will concentrate on obtaining smaller gate geometries. Because of the relatively low electron mobility of 6H-SiC, the gate lengths should be 1 μm or less in order to obtain good high frequency characteristics. The shortest gate length devices that have been fabricated to date have been 1.8 μm. Thus, different methods of achieving finer lines will be developed, incorporating the use of both conventional and eximer laser steppers that should allow 0.6 μm lines to be defined. When the parasitics are reduced to a reasonable level, larger devices will be designed and fabricated so that the previously discussed high power levels may be achieved. In addition to the MESFET research, IMPATT diodes are also currently being fabricated that should yield much better avalanche characteristics than have been observed previously. These devices are designed to operate at high power in the 60 GHz range.

Because the state of the surface is a critical factor in contact studies, an immediate priority is to achieve clean surfaces of good microstructural quality. Cree Research has agreed to grow epitaxial layers on the SiC substrates. Access to a remote hydrogen plasma system has been negotiated, and the effects of this plasma on the SiC surface will be studied.

Similar deposition and annealing experiments will be performed and studied for different annealing times. Specimens are currently being prepared for cross sectional TEM. High resolution TEM will serve to identify phases and microstructure. Electrical characteristics will be quantified by both current-voltage measurements and internal photoemission.

Construction of the MBE/ALE system shall be completed within the calendar year. Characterization of plasmas obtained from all ECR plasma sources will be performed, and characteristics will be optimized. Initial experiments will be run to determine optimum growth conditions for gas-source MBE of monocrystalline SiC on α-SiC. These will consist of varying substrate temperature and flow rates of Si and C source gases for growth on both the (0001) Si face and $(000\bar{1})$ C face of 6H-SiC. Characterization of these films using electron and optical microscopy as well as electrical measurements will be performed. In addition, chemical analysis using

secondary ion mass spectrometry (SIMS) may be performed to determine concentrations of trace impurities. N- and p-type doping of SiC using nitrogen and aluminum will also be conducted.

(7) Listing:

A. Publications

Papers Submitted to Refereed Journals (and not yet published)

1. C. S. Chang, N. J. Zheng, I. S. T. Tsong, Y. C. Wang and R. F. Davis, "Studies of β-SiC (001) and (111) Surfaces by Scanning Tunneling Microscopy," submitted to the Journ. Vac. Sc. and Technol.
2. C. S. Chang, N. J. Zheng, I. S. T. Tsong, Y. C. Wang and R. F. Davis, "Scanning Tunneling in Microscopy of Cubic Silicon Carbide Surfaces," submitted to Journ. Appl. Physics.
3. R. J. Trew, J. B. Yan, and P. M. Mock, "The Potential of Diamond and SiC Electronic Devices for Microwave and Millimeter-WavePower Application," (Invited), IEEE Proc., Special Issue on Wide Bandgap Semiconductors, to be published early 1991.

Papers Published in Refereed Journals

1. K. Das, H. S. Kong, J. B. Petit, J. W. Bumgarner, R. F. Davis and L. G. Matus, "Deep-level Dominated Electrical Characteristics of Au Contacts on Beta-SiC," Journal of the Electrochemical Society, **137**, 1598 (1990).
2. R. F. Davis, "Diamond and Silicon Carbide Thin Films: Present Status and Potential as Wide Band Gap Semiconducting Materials," Intern. Journ. of Materials and Product Technol. **4**, 81 (1989).
3. R. F. Davis, "Epitaxial Growth and Doping of and Device Development in Monocrystalline Beta-SiC Semiconductor Thin Films," Thin Solid Films **181**, 1 (1989).
4. H. S. Kong, J. T. Glass and R. F. Davis, "Growth Rate, Surface Morphology and Defect Microstructures of Films Grown on 6H-SiC Substrates Via Chemical Vapor Deposition," Jour. Materials Research **4**, 204 (1989).
5. K. More, H. Kong, J. T. Glass and R. F. Davis, "Electron Microscopy of Defects in Epitaxial Beta-SiC Thin Films Grown on Silicon and Carbon (0001) Faces of Alpha-SiC Substrates," Journ. of the Am. Ceram. Soc., **73**, 1283 (1990).
6. J. W. Palmour, B. E. Williams, P. Astell-Burt and R. F. Davis, "Crystallographic Etching Phenomenon During Plasma Etching of SiC (100) Thin Films in SF_6," J. Electrochem. Soc., **136**, 491 (1989).
7. J. W. Palmour, R. F. Davis, H. S. Kong, S. F. Corcoran and D. P. Griffis, "Dopant Redistribution During Thermal Oxidation Monocrystalline Beta-SiC Thin Films," Jour. Electrochemical Society **136**, 502 (1989).
8. J. Ryu, H. J. Kim, J. T. Glass and R. F. Davis, "The Effects of Thermal Annealing on the Microstructural, Optical and Electrical Properties of Beta Silicon Carbide Thin Films Implanted with Boron and Nitrogen," Jour. Electronic Materials **18**, 157 (1989).
9. T. Tachibana. H. S. Kong, Y. C. Wang and R. F. Davis, "Hall Measurements as a Function of Temperature on Monocrystalline SiC Thin Films," Journal of Applied Physics, **67**, 6375 (1990).

10. L. A. Tang, J. A. Edmond, J. W. Palmour and C. H. Carter, Jr., "Discrete Devices in 6H-Silicon Carbide," Extended Abstracts of 176th Meeting of Electrochem. Soc.
11. Y. C. Wang, H. S. Kong, J. T. Glass and R. F. Davis, "Atomic Arrangement of the Substrate Surface and Its Effect on Interfacial and Bulk Character of CVD Monocrystalline SiC Thin Films," Journ. of the Am. Ceram. Soc., **73**, 1289 (1990).

Books (and sections thereof) Submitted for Publication

1. R. F. Davis, "Large Bandgap Semiconductor Materials and Devices" to be published in *High-Temperature Electronics*, R. K. Kirschman, Ed., IEEE Press.
2. R. F. Davis, J. W. Palmour and J. A. Edmond, "A Review of the Status of Diamond and SiC Devices for High Temperature and High Frequency Applications," to be published in *IEDM Technical Digest.*
3. R. F. Davis, "Correlation Among Process Routes, Microstructures and Properties of Chemically Vapor Deposited Silicon Carbide," to be published in *Chemical Vapor Deposition of Refractory Metals and Ceramics*, T. M. Bessman and B. M. Gallois, eds., 1990.
4. R. F. Davis, "Recent Advances Regarding the Definition of the Atomic Environment, Thin Film Growth and Microelectronic Device Development in Monocrystalline SiC," accepted for publication in the *NATO Advanced Workshop on the Physics and Chemistry of Carbides, Nitrides and Borides*, R. Freer, ed. Kluwer Academic Publishers, Dordrecht, The Netherlands, 1990.
5. C. Wang, J. Bernholc and R. F. Davis, "Native Defects, Diffusion, Self-Compensation and Boron Doping in Cubic Silicon Carbide" in *Diamond, Boron Nitride, Silicon Carbide and Related Wide Bandgap Semiconductors*, Mater. Res. Soc. Symp. Proc. Vol. **162**, J. T. Glass, R. F. Messier and N. Fujimori, eds., Materials Research Society, Pittsburgh, PA, 1990.
6. K. Das, H. S. Kong, J. B. Petit, J. W. Bumgarner, L. G. Matus and R. F. Davis, "Deep-level Dominated Electrical Characteristics of Au Contacts on Beta-SiC," in *Diamond, Boron Nitride, Silicon Carbide and Related Wide Bandgap Semiconductors*, Materials Research Soc. Symp. Proceed. **162**, J. T. Glass, R. F. Messier and N. Fujimori, 1990.
7. R. F. Davis, J. W. Palmour and J. A. Edmond, "Epitaxial Growth and Doping of Device Development in Monocrystalline Beta- and Alpha-SiC Semiconductor Thin Films," in *Diamond, Boron Nitride, Silicon Carbide and Related Wide Bandgap Semiconductors*, to be published in Materials Research Soc. Symp. Proceed. **162**, J. T. Glass, R. F. Messier and N. Fujimori, eds. 1990.
8. R. F. Davis and J. T. Glass, "The Growth and Characterization of SiC and Diamond for Microelectronic Applications," accepted for publication in *Advances in Solid-State Chemistry.*

Books (and sections thereof) Published

1. A. Antonelli, C. Wang, J. Bernholc and R. F. Davis, "Native Defects in Diamond, SiC, and Si: Energetics and Self-Diffusion," in *Atomic Scale Calculations in Materials Science*, Mater. Res. Soc. Proceed, **141**, J. Persoff, D. Vanderbilt and V. Vitek, eds., Materials Research Society, Pittsburgh, PA, 1989, pp. 249-55.
2. R. F. Davis, "Thin Film Growth, Device Fabrication and New Research Trends in Silicon Carbide for Micro- and Opto-electronics Applications," in *Proceed.*

Intern, Hi-tech Forum, Osaka, H. Hamakawa, ed., Inter Group Corp., Osaka, Japan, 1990, pp. 50-59.

3. R. F. Davis, "Silicon Carbide and Diamond Semiconductor Thin Films: Growth, Defect Analysis and Device Development," in *Proceedings of the High Frequency Power Conversion '89 Conference*, K. Shenai, ed., Intertec Communications, Inc. Ventura, CA, 1989, pp. 128-137.
4. J. A. Edmond, R. F. Davis, S. P. Withrow, "Structural Characterization of Ion Implanted Beta-SiC Thin Films," in *Ceramic Transactions*, Vol. 2, Silicon Carbide, 1987, J. D. Cawley and C. E. Semler, eds., American Ceramic Society, Westerville, OH, 1989, pp. 478-90.
5. H. J. Kim, H. Kong, J. A. Edmond, J. T. Glass, and R. F. Davis, "Chemical Vapor Deposition, *In Situ* Doping and MESFET Performance of Beta-SiC Thin Films, in *Ceramic Transactions*, Vol. 2, Silicon Carbide, 1987, J. D. Cawley and C. E. Semler, eds., American Ceramic Society, Columbus, OH, 1989, pp. 457-78.
6. J. W. Palmour, P. Astell-Burt, R. F. Davis, and P. Blackborow, "Effects of Cathode Materials and Gas Species on the Surface Characteristics of Dry Etched Monocrystalline Beta-SiC Thin Films," in *Ceramic Transactions*, Vol. 2, Silicon Carbide, 1987, J. D. Cawley and C. E. Semler, eds., American Ceramic Society, Westerville, Oh, 1989. pp. 491-500.

B. Presentations

Invited Presentations at Topical or Scientific/Technical Society Conferences

1. R. F. Davis, Annual Meeting of the Materials Research Society, "Correlation Among Process Routes, Microstructures and Properties cf Chemically Vapor Deposited Silicon Carbide," Materials Research Society, Boston, MA, November 27-30, 1989.
2. R. F. Davis, Annual Meeting of the Materials Research Society, "Epitaxial Growth and Doping of and Device Development in Monocrystalline Beta- and Alpha-SiC Semiconductor Thin Films," Materials Research Society, Boston, MA, November 27-30, 1989.
3. R. F. Davis, Kansai Regional Physics Colloquium on SiC, "Recent Developments in the Growth and Device Development in SiC Microelectronics," Kansai Society of Applied Physics, Osaka, Japan, February 2, 1990.
4. R. F. Davis, International Hi-Tech Forum, Osaka, "Thin Film Growth, Device Fabrication and New Research Trends in Silicon Carbide for Micro- and Opto-electronics Applications," Osaka, Japan, 1990.
5. R. F. Davis, "Silicon Carbide and Diamond Devices, Their Potential, Promise and Reality," American Carbon Society, Workshop on Diamond and Diamond-like Materials, Quail Hollow, OH, May 24, 1990.

Contributed Presentations at Topical or Scientific/Technical Society Conferences

1. J. A. Edmond, "Discrete Devices in 6H-SiC," 1989 Electrochemical Society Meeting in Hollywood, Florida, October, 1989).

2. J. W. Palmour, "High Temperature Devices in 6H-SiC," Invited Presentation in the "High Temperature Semiconductors" session of the 1990 March Meeting of the American Physical Society, March 15, 1990.

C. Patents Filed: none
Patents Granted: none

D. Honors/Awards: R. F. Trew, Area of National Need Electronic Materials Fellowship

(8) Participants:

NCSU:	Dr. R. F. Davis (Materials Science and Engineering)
	Dr. R. J. Trew (Electrical and Computer Engineering)
Graduate Students:	Lisa Spellman
	Larry Rowland
	Yu Cheng Wang
Post Doctoral Fellows:	Benda Yan
Cree Research, Inc.:	Dr. John Palmour (Senior Scientist)
	Dr. Calvin H. Carter, Jr. (Director of Technology)